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KOPE AND FAIRVIEW RIPPLE MARKS: BROWN AND ADAMS COUNTIES, OHIO¹

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ABSTRACT

The directional data of cross-laminae and ripple marks in the Kope and Fairview Formations in Brown and Adams Counties, Ohio, show no statistically significant difference in mean orientation. The prevailing paleocurrent direction was towards the north-northwest. A significant difference, however, exists between the wave lengths of the ripples in the Kope and Fairview. Ripple marks are larger in the Kope Formation and gradually decrease in size upward into the overlying Fairview Formation. This may well have resulted from gradual local shallowing of the Cincinnati sea as carbonate detritus accumulated. The ripple marks are interpreted to have been formed by currents and modified by waves.

INTRODUCTION

The sequence of siltstones, shales, and highly fossiliferous limestones that crops out in southwestern Ohio, southeastern Indiana, and northern Kentucky, and that includes the type section of the Upper Ordovician Cincinnati Series, has been the subject of numerous investigations. Early reports dealt primarily with general geology and systematic paleontology. More recently a number of papers have been published on lithostratigraphy (Ford, 1967; Peck, 1966; Osborne, 1968). Rather few studies have been conducted on the primary sedimentary structures, especially those on the east side of the Cincinnati arch.

Careful study and analysis of primary sedimentary structures, combined with stratigraphic data, should reveal paleoslope and direction of transport of sediments. Therefore systematic observations were made on ripple marks and cross-laminae, and the data were analyzed quantitatively. The directional significance of these primary sedimentary structures is displayed for each of several subdivisions of the Kope and Fairview Formations. The study was designed similarly to those of Hofmann (1966b) and of Osborne (1968); the results of this study are compared with theirs from areas just west of and on top of the Cincinnati arch.

METHODS

Field work was done in 1966 in the Ohio parts of the Higginsport, Russellville, Maysville West, and Maysville East 7.5-minute quadrangles (fig. 1). All exposures were carefully examined for primary sedimentary structures, among which

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cross-laminae and ripple marks dominate. Because outcrops are almost wholly confined to road cuts and creek beds, a geographically uniform sampling pattern could not be obtained.

Ripple marks were distinguished as symmetrical or asymmetrical in the field, and ripple heights, wavelengths, and azimuths of the crests were measured. Ripple height is the vertical distance from a ripple crest to the bottom of an adjacent trough; wavelength is the horizontal distance between adjacent crests. The ratio of wavelength to ripple height, the "vertical-form index" of Bucher (1919), was calculated for each ripple measured. A total of 695 measurements

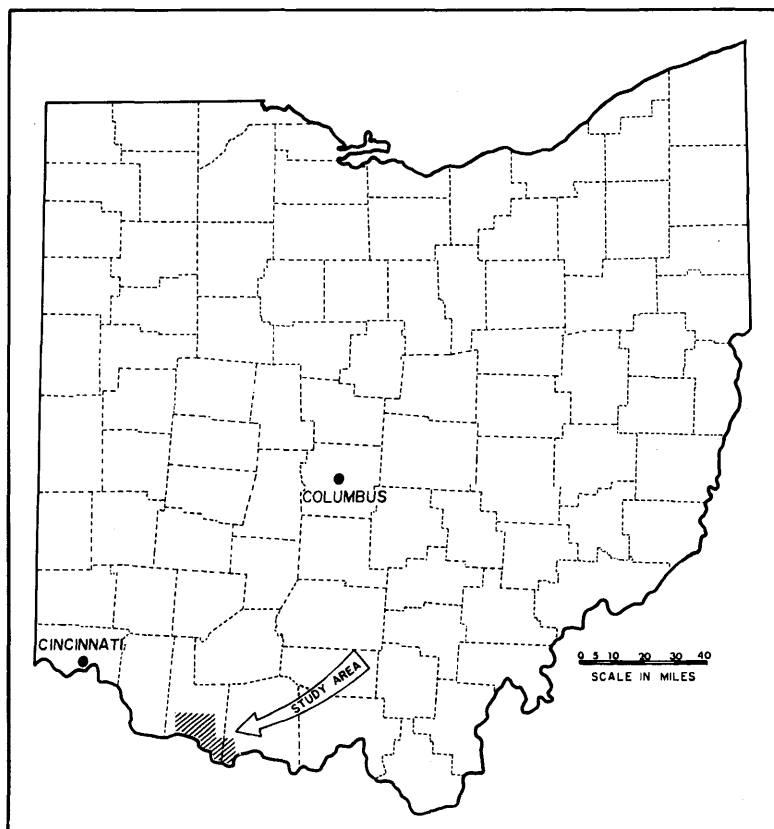


FIGURE 1. Index map.

of ripple trend were obtained from 101 different exposures. Usually several measurements were made on a single rippled bed at each locality. Some of the rippled limestone beds are cross-laminated, and thereby yield additional directional information.

For stratigraphic control of directional data, each formation was divided arbitrarily into lower, middle, and upper thirds (see Tables 1 through 5). Such division permitted testing of variability of structures within, as well as between formations. Oriented samples of ripple-marked limestone were collected at nearly every locality for detailed fabric analysis by transmitted infrared photography (Ali and Weiss, 1968b).

STRATIGRAPHY

The lowest fully exposed unit in the area studied is a sequence of pelitic rocks with a subordinate amount of limestone: the Kope Formation (Weiss and Sweet, 1964; Weiss and others, 1965), formerly called Eden shales. Shales comprise 75 to 80 percent of the formation, are bluish- to brownish-gray and thin-bedded, and alternate with thin slabby limestones. The shales generally appear massive when dry, and fissile when wet. Lateral changes in thickness of individual beds

TABLE 1

Statistical Summary of Observations on Ripple Marks Wavelengths (in CM)

	Fairview				Kope				Total Kope and Fairview
	Total Fairview	Lower Third	Middle Third	Upper Third	Total Kope	Lower Third	Middle Third	Upper Third	
Number of Observations	164	42	59	63	238	53	64	121	402
Mean Wave Length	59.1	58.6	61.2	57.5	86.3	92.6	84.5	84.3	75.2
Maximum λ	121.9	121.9	79.2	86.3	188.9	177.8	155.8	188.9	188.9
Minimum λ	22.8	44.5	42.3	22.8	42.6	47.8	42.6	54.8	38.1
Standard Deviation	11.7	15.5	7.8	8.1	23.7	28.2	27.0	20.2	24.0
Coefficient of Variation	19.7	26.4	12.7	14.0	27.0	30.4	31.9	23.9	31.9

TABLE 2

*Statistical Summary of Observations on Ripple Marks
Ripple Indexes*

	Fairview				Kope				Total Kope and Fairview
	Total Fairview	Lower Third	Middle Third	Upper Third	Total Kope	Lower Third	Middle Third	Upper Third	
Number of Observations	233	42	74	117	161	38	59	64	399
Mean Ripple Index	13.4	13.8	13.9	12.9	12.6	12.6	12.2	12.9	12.9
Maximum Ripple Index	28.9	26.9	28.9	23.0	28.7	26.6	16.0	28.7	28.9
Minimum Ripple Index	6.8	7.5	8.2	6.8	6.5	6.5	6.2	6.0	6.0
Standard Deviation	4.1	4.4	4.6	3.5	4.0	3.9	2.7	5.0	4.1
Coefficient of Variation	30.5	31.8	33.0	27.1	31.7	30.9	22.1	38.7	31.7

are common. The limestones occur as discontinuous beds and are bluish-gray to gray, fossiliferous, medium-grained, locally silty, and poorly to well sorted. The Kope Formation is about 200 feet thick in the area studied. The subjacent Lexington Limestone (Point Pleasant) is poorly exposed in the area, and contains few directional features.

The Fairview Formation, which overlies the Kope Formation conformably, consists of interbedded bluish-gray limestone (about 60 percent) and shale. Shell-

hash limestones with little insoluble fractions, classes 1, 2, and 4 of Weiss and Norman (1960), seem to dominate in the lower part of the formation, whereas highly fossiliferous, medium-bedded silty limestones (class 3) and fine-grained unfossiliferous silty limestones (class 5) prevail higher up. Many joints cut the

TABLE 3
Test of Variances Between Wavelengths From Different Stratigraphic Units

Units Compared	F	Degree of Freedom d.f.		Probability of Difference Having Arisen by Chance P
		Numerator	Denominator	
Kope vs. Fairview	4.10	237	163	<0.01
Lower Third Kope vs. Upper Third Fairview	12.11	52	62	<0.01
Lower Third Kope vs. Middle Third Fairview	3.31	52	58	<0.01
Middle Third Fairview vs. Upper Third Fairview	3.66	58	62	<0.01
Lower Third Fairview vs. Middle Third Fairview	3.94	41	58	<0.01
Upper Third Kope vs. Lower Third Fairview	1.69	120	41	0.05
Middle Third Kope vs. Upper Third Kope	1.78	63	120	0.01
Lower Third Kope vs. Middle Third Kope	1.09	52	63	>0.20

TABLE 4
Test of Significance Between Wavelengths From Different Stratigraphic Units

Units Compared	t	Degree of Freedom d.f.	Probability of Difference Having Arisen by Chance P
Kope vs. Fairview	13.596	400	<0.001
Lower Third Kope vs. Upper Third Fairview	-9.434	114	<0.001
Lower Third Kope vs. Middle Third Fairview	-8.214	110	<0.001
Middle Third Fairview vs. Upper Third Fairview	2.567	113	0.01-0.02
Lower Third Fairview vs. Middle Third Fairview	-1.108	99	0.2-0.3
Upper Third Kope vs. Lower Third Fairview	7.508	161	<0.001
Lower Third Kope vs. Middle Third Kope	1.583	115	0.1-0.2

limestones throughout the formation. Rhythmically interbedded with the limestones are pelitic rocks at intervals of not more than 1.5 to 2 feet. Shale prevails among the pelitic rocks, but laminated unfossiliferous limy siltstones make up about 30 percent of them. These siltstones are locally contorted into flow-beds.

The Fairview Formation is 70 to 80 feet thick in most of the area studied. The superjacent Grant Lake Limestone (Peck, 1966, p. 14) is incompletely exposed in the area studied and has few directional features.

RIPPLE MARKS

Ripple marks are the common directional feature in both the Kope and Fairview Formations, and are virtually absent from the Lexington and Grant Lake Formations. A minority of the ripple-marked beds are also cross-laminated; these give the best information on paleocurrents. Such internal structures are not conspicuously developed, and show only on favorably weathered surfaces. Other directional features, such as flow-beds, are even less common than are cross-laminated ripple marks, and are also less reliable in the reconstruction of directions of paleocurrents. Accordingly, inferences about paleoslope and current directions were derived mostly from the forms of the ripple marks, were confirmed wherever

TABLE 5

Test of Significance Between Ripple Indexes From Different Stratigraphic Units

Units Compared	t	Degree of Freedom d.f.	Probability of Difference Having Arisen by Chance P
Kope vs. Fairview	1.923	392	.05-.1
Lower Third Fairview vs. Upper Third Fairview	-0.950	104	0.3-0.4
Lower Third Fairview vs. Middle Third Fairview	-2.261	99	0.02-0.05
Middle Third Fairview vs. Upper Third Fairview	-0.955	121	0.3-0.4
Lower Third Fairview vs. Middle Third Fairview	0.597	95	0.5-0.6
Upper Third Kope vs. Lower Third Fairview	0.446	152	0.6-0.7
Middle Third Kope vs. Upper Third Kope	1.700	189	0.05-0.1

the ripples were cross-laminated, and were supported wherever flow-beds occurred.

Data concerning ripple marks in the area studied were obtained from 101 naturally exposed rippled limestone beds, probably a minority of the real population of rippled beds. Seventy of these beds occurred in the Kope Formation and 31 in the Fairview Formation. For convenience in comparing samples, the entire area was divided into rectangular blocks of approximately 2.0 x 2.2 miles.

Two types of ripple marks, each associated with particular limestones, occur in the area. The first are small interference ripples with wavelengths of 15 to 20 cm and ripple heights of 6 to 10 mm; these are generally formed on fine-grained, dense, silty limestones (type 6 of Weiss and Norman, 1960). These ripples typically consist of two or more sets of intersecting crests and bear a complex relationship to current direction (fig. 2). The second type, mostly of large size (fig. 3) with an average wavelength of 76 cm and an average ripple height of 7 cm, is confined to limestones of type 1 or 2 and sometimes 3 (Weiss and Norman, 1960). These large ripple marks have been called *pararipples* (Bucher, 1919, p. 263) and *megaripples* (Potter, 1961, p. 263), and are "dunes" in the scheme of Simons and others (1965), but in this report the simple non-genetic term "large ripple marks" is used. Ripple marks seem to be most abundant in the middle

and upper thirds of the Kope Formation (fig. 4), perhaps because of greater abundance of exposures of the middle and upper Kope Formation in the area. The genesis of large ripple marks has been considered by many workers; a recent review (Weiss *et al.*, 1965, p. 54) concludes that they were formed by currents and modified by waves.

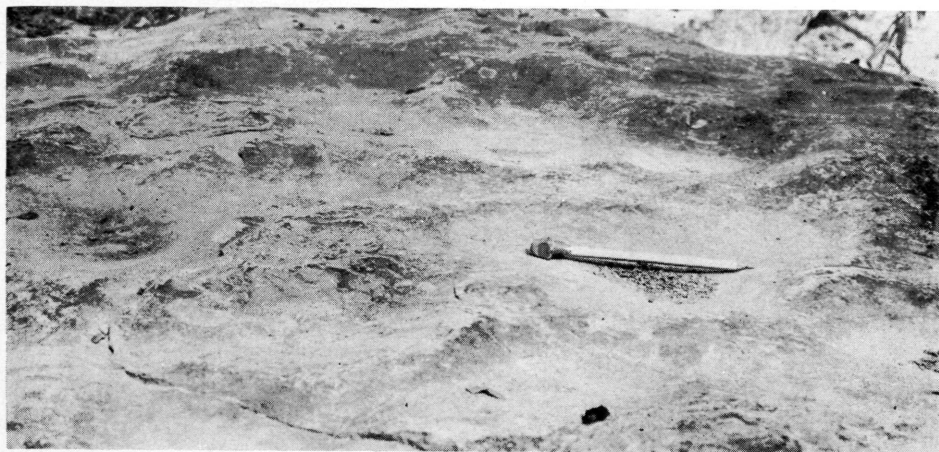


FIGURE 2. Interference ripple marks in middle Fairview calcarenite. Elevation of 575 feet on Little Threemile Creek, Maysville East quadrangle.

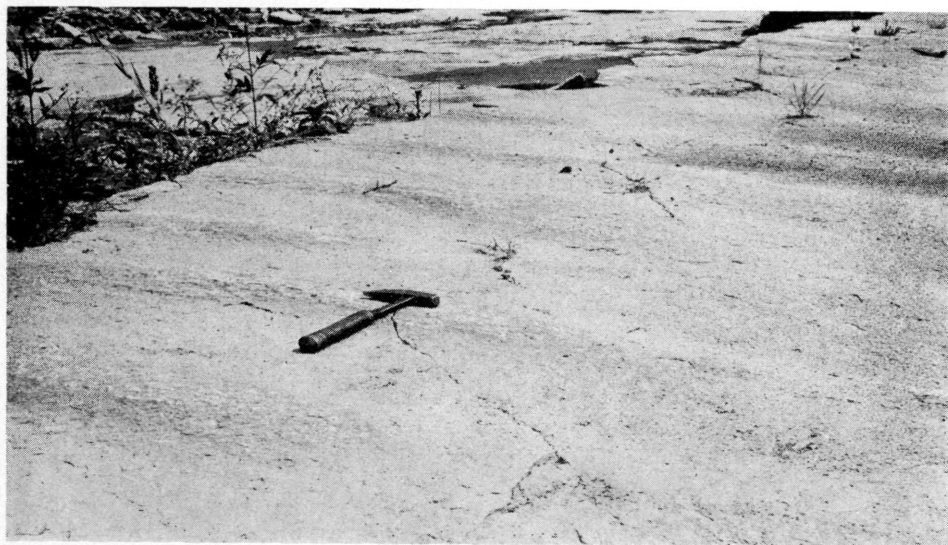


FIGURE 3. Symmetrical ripple marks in upper Kope calcarenite; crests are rounded, and symmetrical shape of crests and troughs is easily seen. Elevation of 610 feet on Big Threemile Creek, Maysville East quadrangle.

Most of the large ripple marks on any bed in the area studied have relatively straight, sub-parallel crests, and the range of azimuths about the mean direction for each bed is generally less than 25° to either side. Most symmetrical and asymmetrical ripples have broadly rounded crests. The majority of Kope and

Fairview ripple marks are symmetrical. The symmetrical ripples display a variety of cross-sectional shapes, but most are modifications of typical symmetrical ripple marks, having small, rounded crests and broad flat bottoms (fig. 3). A few ripples in the Kope and Fairview are clearly asymmetrical in cross-section (Weiss and others, 1965, pls. 7, 8), and have cross-laminae that dip normal to the trends of ripple crests. Dips of the cross-laminae generally do not exceed 35° . Some

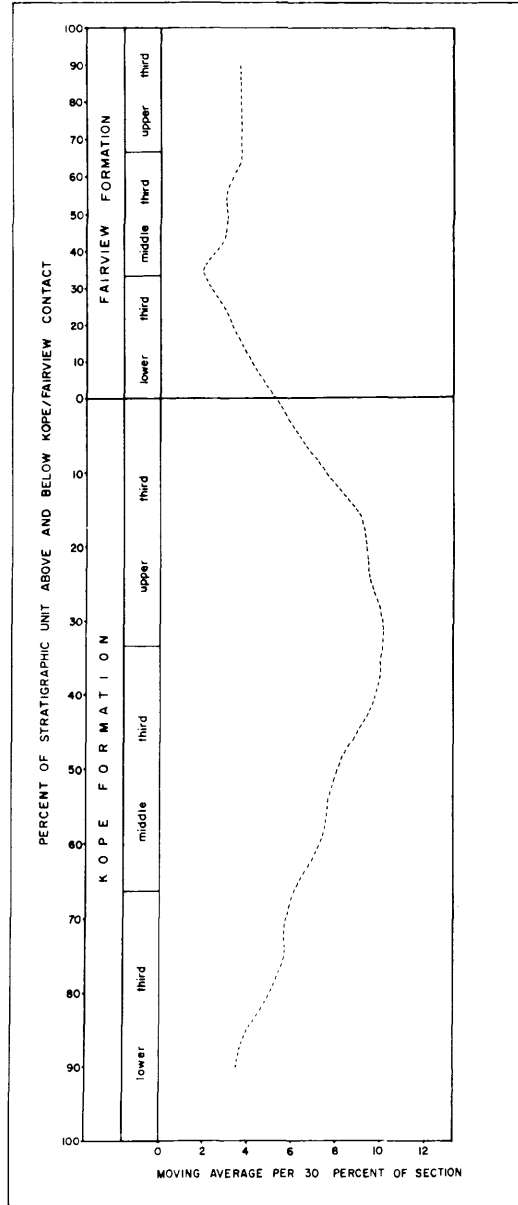


FIGURE 4. Abundance of large ripple marks in Kope and Fairview Formations. Abundance is shown as moving average of number of ripples observed per successive internal of stratigraphic thickness; each interval is 30 percent of the formation thicknesses.

of the asymmetrical ripples grade into symmetrical ones along their length. Symmetrical forms associated with cross-laminae appear to confirm that these are current ripples that were modified later by reversal of currents (Bucher, 1919, p. 264-265). Most symmetrical ripples, weathered or not, display no obvious cross-laminae. Hofmann (1966b, p. 871) showed that several combinations of dip of laminae and ripple form exist. Our observations confirm his; only dip of laminae and strike of ripples can be used for paleocurrent studies based on ripples.

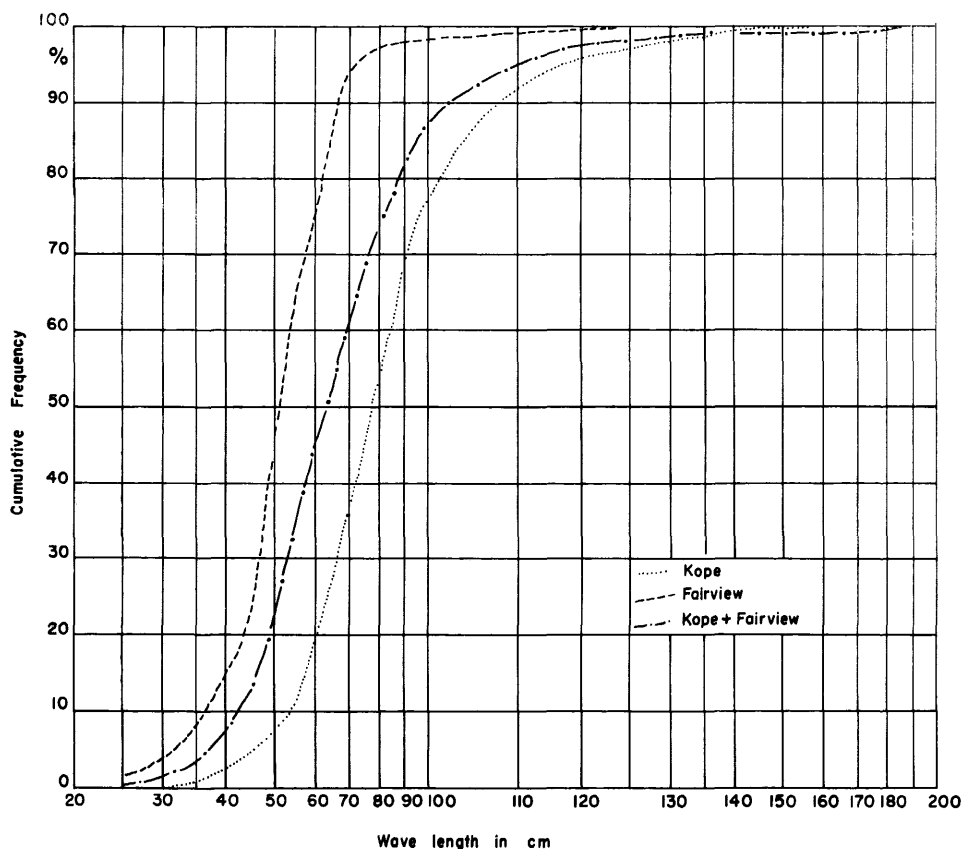


FIGURE 5. Cumulative frequency curves for wave lengths.

Some parallel disconnected spindle-shaped masses of silty limestone occur in the middle Fairview along the highway 2.5 miles north of Ripley. They are incomplete ripples, with "pinch-and-swell" cross-sections, that developed because insufficient sand-sized carbonate material was available to form a continuous limestone stratum; in the troughs of the ripple forms, subjacent and superjacent pelitic beds meet. Hofmann (1966b, p. 871) observed similar structures in western Hamilton County.

The measurements of external features of the ripple marks are summarized in Tables 1 and 2. The cumulative frequency curves and histograms for wavelengths and ripple indexes (figs. 5 and 6, and figs. 7 and 8) clearly indicate the high variability of the data, although wavelengths are less variable than are ripple indexes. Hofmann (1966b) suggested that the higher variability in the ripple indexes may be a result of differential erosion, by lowering the heights of some ripples.

A preliminary statistical analysis by means of rose diagrams (fig. 9) indicates that most azimuths of individual ripples lie within a span of less than 90°. This appears to justify the assumption that most of the ripple marks measured are from the same population and can therefore be compared with each other. To

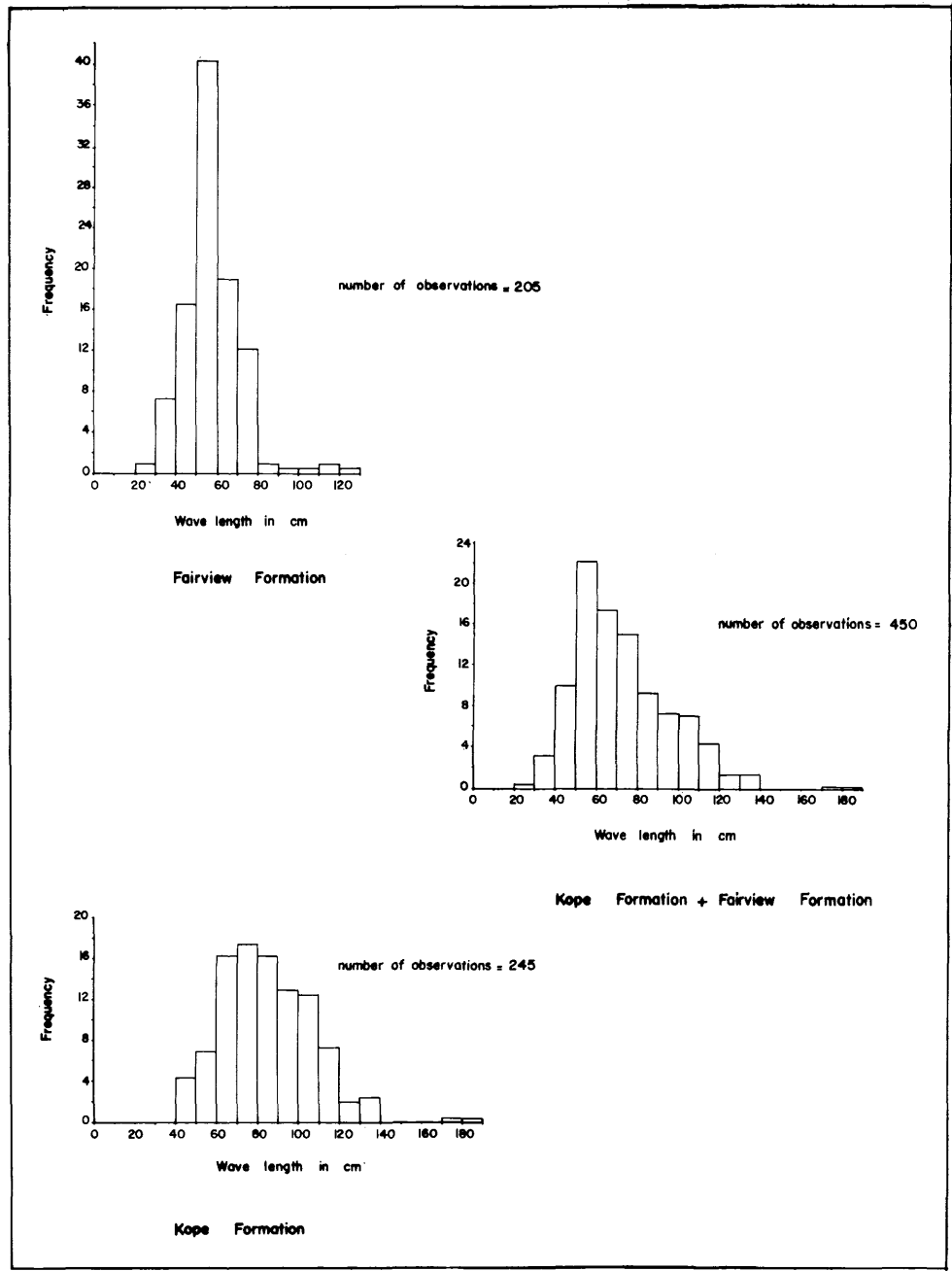


FIGURE 6. Histograms of Kope and Fairview ripple mark wave lengths.

pave the way for further statistical analysis, the standard deviations, coefficients of variation, and means were calculated for both wavelengths and ripple indexes; these are summarized in Tables 1 and 2. Snedecor's F-test was then performed, using the formula given by Simpson and others (1960, p. 185).

The F-test was used prior to the t-test to determine whether the sample variances were sufficiently alike to justify the assumption that they are independent estimates of the same population variance. The results of the F-test (Table 3) indicate that the differences between the standard deviations of wavelengths of ripples in the Kope, Fairview, and their stratigraphic subdivisions are statistically significant.

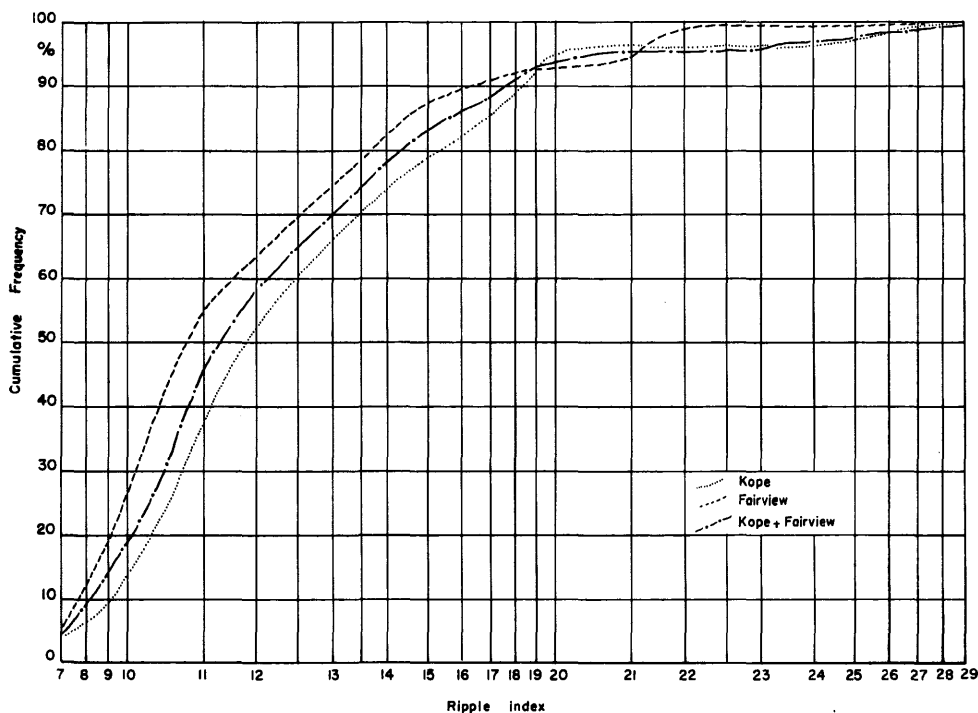


FIGURE 7. Cumulative Frequency curves for ripple indexes.

Student's t-test was then used to test for significant differences in wavelength and ripple index among the different stratigraphic units, using the formula given by Simpson and others (1960, p. 194). Laborious calculations were avoided by programming an analysis for the IBM 7094-1401 computer, using Fortran IV language.

The results of the t-test are shown in Tables 4 and 5. The differences between the wavelengths of the ripple marks in the Kope and in the Fairview Formations are shown to be highly significant. The differences between those of the Kope and Fairview subunits are somewhat less so, and between those of the lower and middle thirds of the Kope Formation are only moderately significant.

These results tend to substantiate an appreciable decrease in ripple wavelengths from the Kope to the upper part of the Fairview, whereas ripple indexes show no significant change throughout the section. Hofmann (1966b) noticed a similar decrease in wavelengths in western Hamilton County.

CROSS-LAMINAE

Twenty-five percent of the large ripples exposed in the area display obvious cross-laminae on weathered surfaces. The laminae show differences in grain size and mineralogy. Discoid brachiopod shells, crinoid columnals, and bryozoans are the abundant platy materials of coarser size. Dips of cross-beds were measured, and oriented samples of each bed were collected for systematic fabric study with transmitted infrared, X-radiography, and fluorescent-dye techniques. Details of these techniques and their applicability to Cincinnati limestones are discussed in Ali and Weiss (1968a; 1968b).

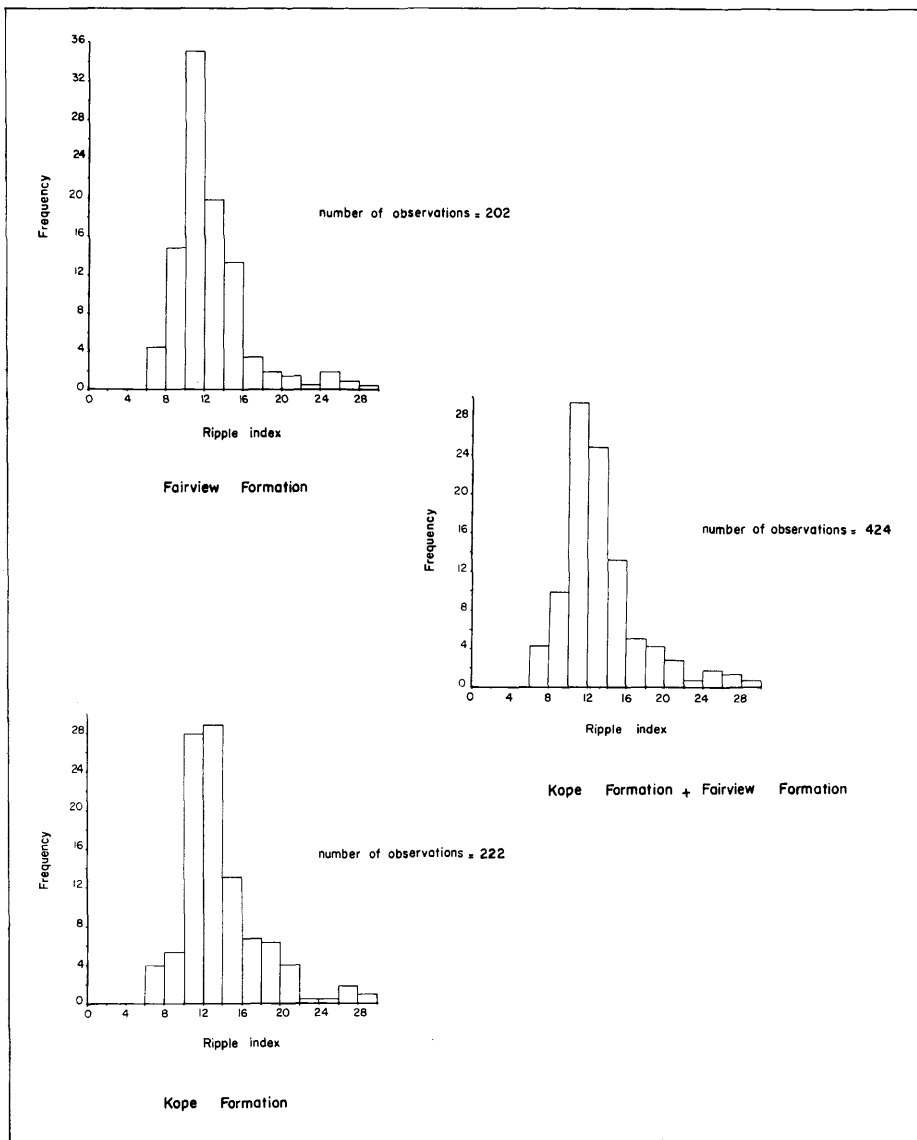


FIGURE 8. Histograms of Kope and Fairview ripple indexes.

Systematic fabric study shows that rippled Fairview and Kope limestones contain two types of cross-laminae, planar and festoon, distinguished on the basis of the geometry of the laminae. About 70 percent of all cross-laminae collected and measured are planar (fig. 10), and about 30 percent are of the festoon type (fig. 11). Planar cross-laminae occur mostly in limestone beds of types 1 and 2 and are rarely in type 4. Festoon cross-laminae are found only in limestone beds of types 4 and 6.

Planar cross-laminae occur if the lower bounding surface is a planar surface of

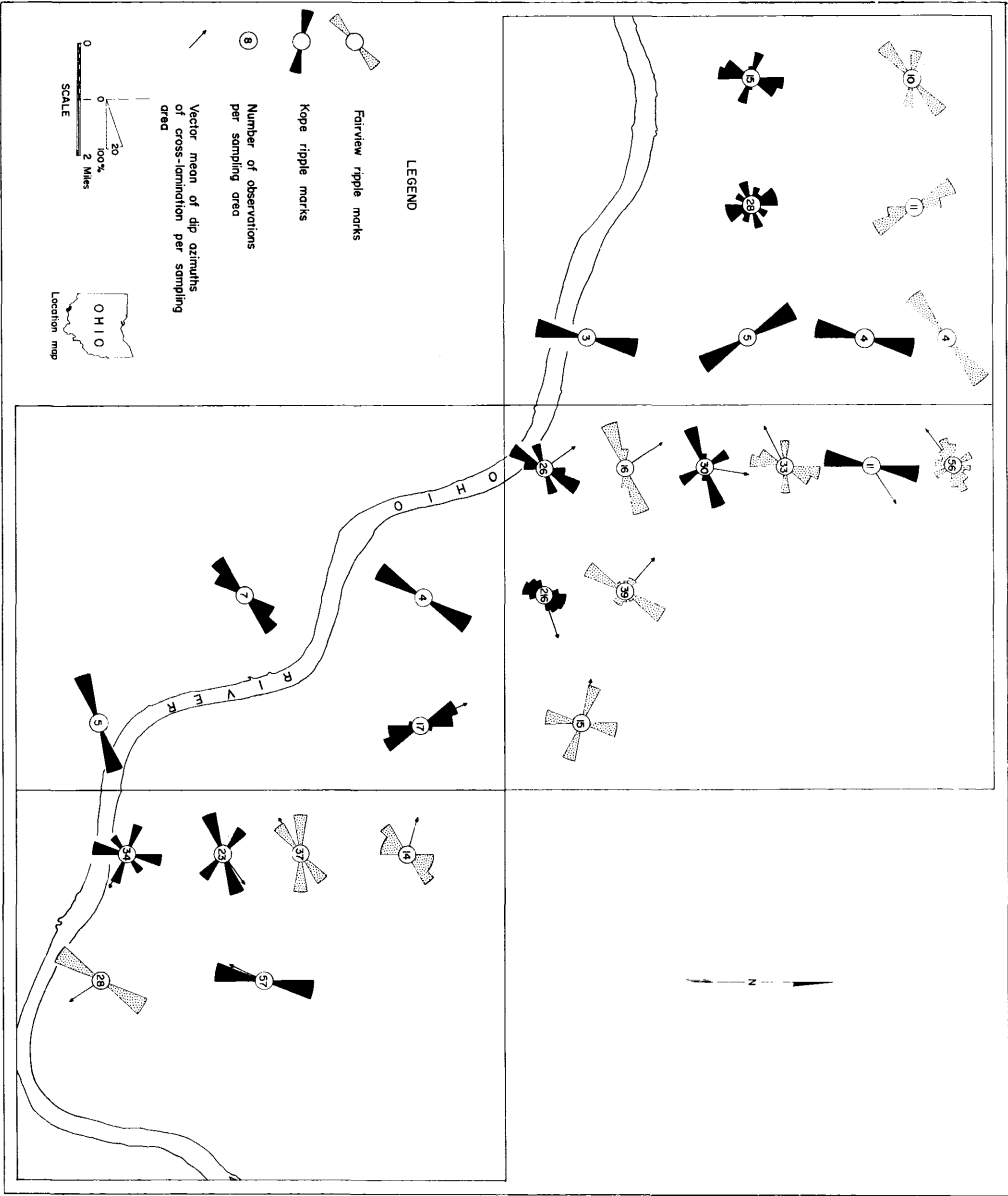


FIGURE 9. Paleocurrent rose diagrams for Kope and Fairview Formations.

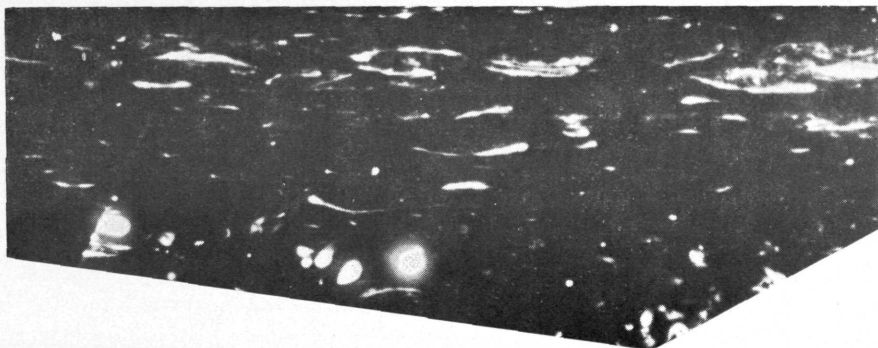


FIGURE 10. Kope shell-hash limestone; planar cross-laminae shown by transmitted infrared light.

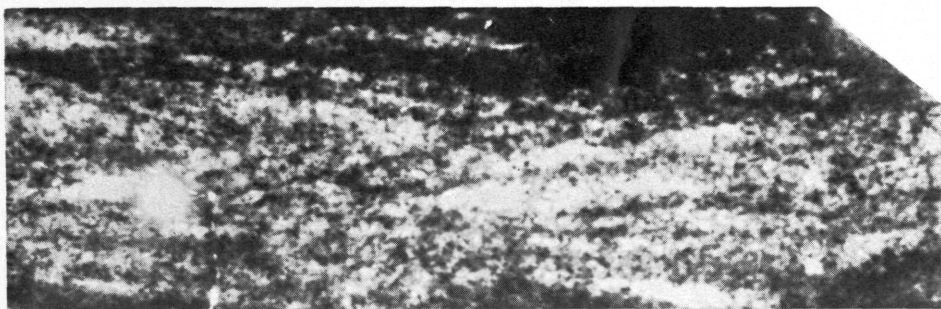


FIGURE 11. Fairview calcarenite; festoon cross-laminae shown by transmitted infrared light.



FIGURE 12. Planar cross-bedding in a single bed of middle-Fairview calcarenite. Hammer handle points in the direction of dip of the cross-beds. Elevation of 575 feet on Little Threemile Creek, Maysville East quadrangle.

erosion caused by beveling and subsequent deposition (McKee and Weir, 1953, p. 385). The cross-laminae are tabular and have a consistent inclination (figs. 10 and 12). It is difficult to describe the angle of inclination in the field, but the angles measured on samples sectioned in the laboratory are good approximations of the true dip. The inclinations of planar cross-laminae were found to range from nearly horizontal to about 25° . Individual sets of planar cross-laminae range in thickness from about 0.1 to 4 cm. Large-scale planar cross-strata also occur in the Fairview Formation (fig. 12), and provide additional directional information.

In the festoon type of cross-lamination, the lower bounding surfaces of the laminae are curved, and the troughs are almost symmetrical when viewed in sections normal to the current direction (fig. 13). Individual sets of festoon cross-laminae range in thickness from 1 to 3 cm. No large-scale festoon cross-strata were observed in the area.

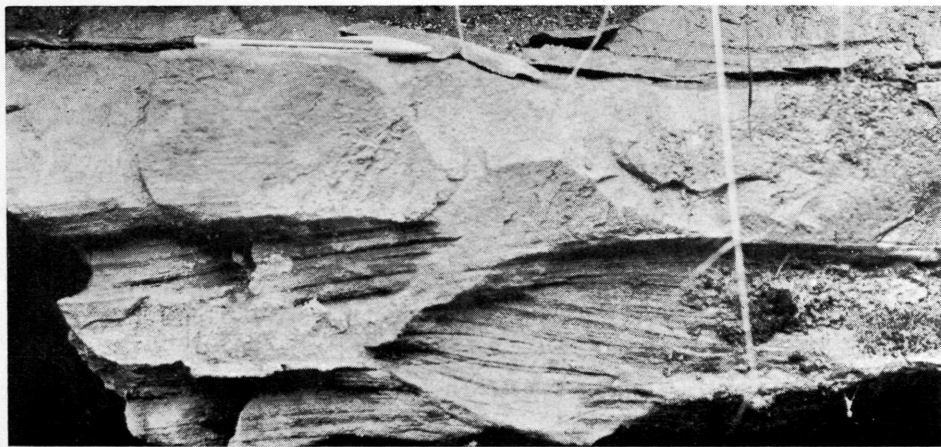


FIGURE 13. Festoon cross-bedding in upper Fairview silty limestone. Elevation of 618 feet on Little Threemile Creek, Maysville East Quadrangle.

Some azimuths of dip of cross-laminae were recorded in the field, and others were measured on samples sectioned in the laboratory. The data were then grouped according to stratigraphic units, and the vector mean and vector strength computed according to the formulae given by Curray (1956, p. 119). Pincus (1956) and Curray (1956) have indicated that both a vector summation and a plot of the vector means are useful in representing periodic data. This approach is advantageous in that it shows average current direction for each stratigraphic division; the resulting pattern is easily understandable and it tends to smooth out local variations. The vector means of the dip azimuths of the cross-laminae for each stratigraphic division are presented in figure 14.

A chi-square test (Durand and Greenwood, 1958) was performed on the ungrouped data of Kope and Fairview cross-laminae to determine the nature of their distribution. The test shows that data from both the Kope and Fairview Formations indicate no evidence for preferred orientation. In western Hamilton County, however, Hofmann (1966b, p. 876-878) detected a weak unimodal preferred orientation for Kope cross-laminae and bimodal preferred orientation for the Fairview.

Snedecor's F-test was performed on the grouped data of cross-laminae to determine whether the sample variances were sufficiently alike to justify use of the t-test. Because the calculated F-value, 1.006, was less than the tabular value of 1.84 for $F_{.95} (22, 30)$, it is clear that the differences between the standard devia-

tions are not significant. The grouped vector data were tested by means of the *t*-test. For 52 degrees of freedom, the observed value of *t* is 1.24, which is smaller than the tabular value of *t* .05, 2.00. Therefore, no significant differences exist at the 95-percent level between the Kope and Fairview current directions. This, in turn, leads to the conclusion that mean current flow in the study area remained generally the same during Kope and Fairview deposition.

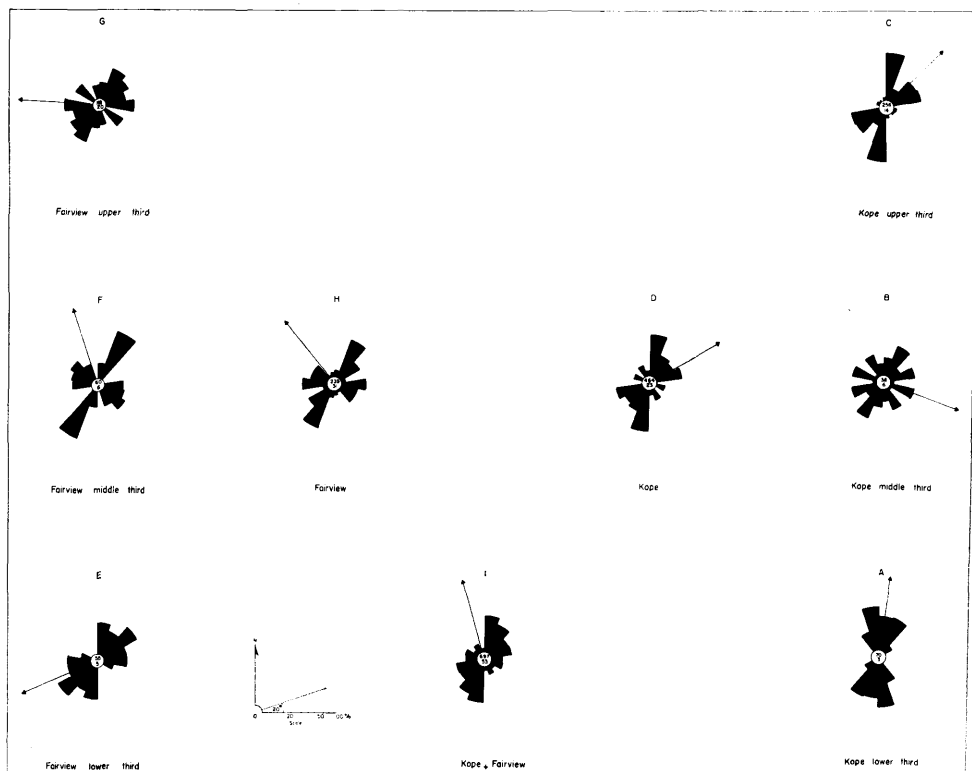


FIGURE 14. Paleocurrent rose diagrams for Kope and Fairview Formations and subdivisions. Upper figure in each rose is number of observations on ripple marks; lower figure is number of observations on cross-laminae. Vector means of cross-laminae are shown by arrows.

INTERPRETATION OF DIRECTIONAL DATA

No obvious trends are apparent when the observed ripple mark and cross-lamination data are plotted on a scatter map (fig. 15). A slightly improved picture evolves when the ripple trends and dip azimuths of cross-laminae are plotted, by formations, as rose diagrams on equiareal polar paper (fig. 9). Here the local variations of Kope and Fairview paleocurrents are quite evident.

A clear distinction between the data from the Kope and from the Fairview Formations develops when the grouped directional data are plotted (fig. 14, D and H). Stratigraphic subdivisions of the formations are arbitrary, but some differences between successive vertical units can be distinguished (fig. 14, A through C, and E through G).

The vector means of grouped data of cross-laminae pertaining to lithic units are shown in Figure 9. The 95-percent confidence intervals for grouped vector

means of dip azimuths for the Kope and Fairview Formations are $59^{\circ} \pm 68^{\circ}$ and $321^{\circ} \pm 57^{\circ}$, respectively.

The equiareal polar paper used in this report was constructed according to the method suggested by Pincus (1953, p. 498). This paper is advantageous in that each circular zone has the same area as each of the others. It therefore prevents the erroneous impression of distribution that ordinary polar paper gives.

In the lower third of the Kope Formation, the ripple-mark distribution is clearly unimodal and the bearing of the modal class is $N10^{\circ}W$ (fig. 14A). The

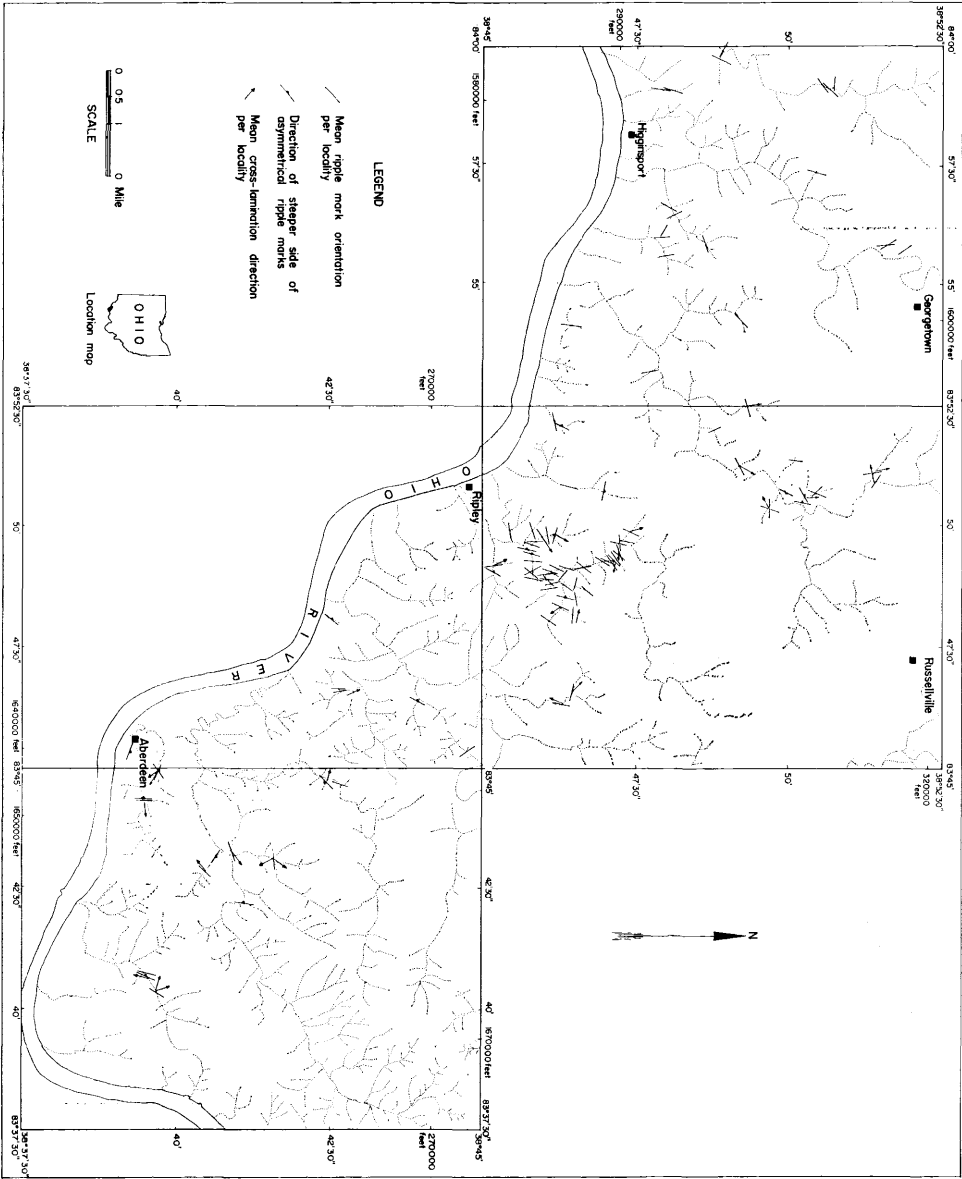


FIGURE 15. Orientation of ripple marks and cross-laminae in the area studied.

mean direction of dip of cross-laminae there is $N5^{\circ}E$. The ripple distribution in the middle third of the Kope Formation is scattered, with a slightly preferred orientation about $N30^{\circ}E$ (fig. 14B). The mean direction of dip of cross-laminae there is $S72^{\circ}E$, which is approximately normal to the bearing of the modal class of ripples. The upper third of the Kope Formation shows a unimodal ripple distribution, and the modal class trends $N10^{\circ}E$ (fig. 14C). The rose diagram for the whole Kope Formation shows a unimodal distribution (fig. 14D) with modal class trending $N10^{\circ}E$. The associated cross-laminae indicate a current directed $N59^{\circ}E$. These data suggest that only minor differences in ripple orientations and paleocurrent directions exist among the units of the Kope Formation.

The lower third of the Fairview Formation also shows a unimodal ripple distribution, with a modal-class trend of $N50^{\circ}E$. The mean direction of dip of the cross-laminae there is $S66^{\circ}W$ (fig. 14E). The ripple-mark distribution in the middle third of the Fairview Formation is bimodal; one modal class trends $N50^{\circ}W$, but the prominent one trends $N30^{\circ}E$. The mean dip direction of cross-laminae there is $N18^{\circ}W$, which is approximately normal to the northeast-trending class (fig. 14F). The upper third of the Fairview Formation also demonstrates a bimodal distribution; the prominent modal class trends $N30^{\circ}E$, and the other trends $N50^{\circ}W$ (fig. 14G). Here the cross-laminae dip $N88^{\circ}W$, which is approximately normal to the northeast-trending modal ripple class. The Fairview Formation as a whole also is bimodal; the more prominent modal class trends $N30^{\circ}E$ and the other $N70^{\circ}E$ (fig. 14H). The associated cross-laminae trend $N39^{\circ}W$.

A rose-diagram (fig. 14I) summarizes all ripple-mark and cross-laminae data. They all display a unimodal tendency, with the modal class having a mean bearing of $N10^{\circ}E$. The mean dip direction of the cross-lamination is directed $N23^{\circ}W$.

PALEOCURRENTS

The Kope and Fairview ripples have a strong northeast ripple trend, perpendicular to the general strike of the Fairview isopach contours (fig. 16). Potter and Pettijohn (1963, p. 95-96) illustrate similar ripple orientations for the full thickness of the Cincinnati strata east of the Cincinnati arch, in portions of Ohio and Kentucky. The average strike of the ripple crests there is $N12^{\circ}E$, and associated cross-laminae dip due west.

The general paleocurrent direction during Kope-Fairview deposition was therefore dominantly toward the north-northwest. Similarly, in eastern Hamilton County, Osborne (1968, p. 2148) found no significant difference in paleocurrent direction throughout Kope and Fairview time, although the currents there bore more to the south.

According to Hofmann (1966b), a significant difference exists in western Hamilton County between the paleocurrent directions observed in the Kope and the Fairview Formations. It seems therefore that differences between the paleocurrent directions recorded for the Kope and the Fairview Formations can be discriminated only locally. Differences in paleocurrent direction between the areas studied by Hofmann (1966b) on the west, and by Osborne (1968) and the present authors on the east may arise from the shoaling nose of Fairview calcarenites in central Hamilton County. West of it the calcarenite tongues thinned and sloped into deeper water in Indiana (Ford, 1967; Hofmann, 1966a, p. 537, figure 7).

ENVIRONMENT OF DEPOSITION

Ample evidence suggests the presence of both deep- and shallow-water depositional environments for the Kope and Fairview Formations. The carbonate strata show characteristics of formation and deposition in a shallow marine environment, whereas pelitic strata have features of deep-water sediments. The terms "shallow" and "deep" are relative and have no specific depth implications. The fact that

cross-laminae and ripple marks are found only in carbonate strata indicates deposition on that part of the sea floor that was stirred and reworked by storm waves. The pelitic strata, which seem to lack these primary structures, were probably deposited on low areas of the sea floor or perhaps those bound by algae.

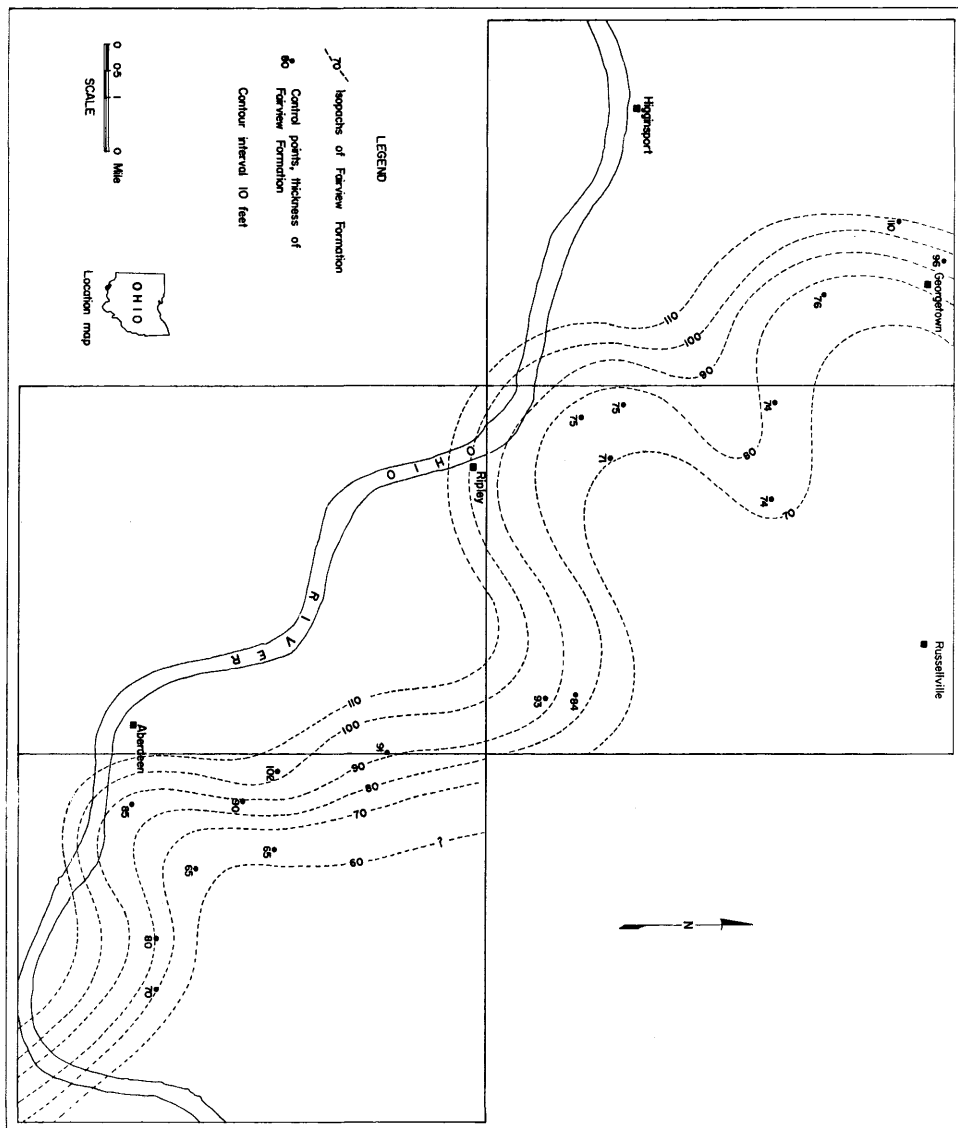


FIGURE 16. Isopach map of Fairview Formation.

The maximum depth of water over the Cincinnati arch during the time of Kope and Fairview deposition has been estimated at 25 meters by Bucher (1917; 1919) on the basis of the magnitude of current-formed pararipples. According to Kuenen (1950, p. 67), tidal currents, sufficient to produce such ripples, are known to occur at depths of 1000 to 2000 meters. These unusually deep currents occur along island arcs, however, where the land-sea configuration is complex and the

submarine topography has fairly high relief (Kuenen, 1950). No such high relief of the Ordovician sea bottom is evident in the Cincinnati region. A graph constructed by Allen (1963, p. 198) relates increasing mean ripple height to increasing water depth. When this relationship is applied to the strata in the Cincinnati area, however, it is necessary to conclude that Kope and Fairview ripples formed in water about one meter deep. The absence of mud cracks makes an environment with such shallow water very doubtful. That the ripple index is about the same throughout the Kope and Fairview Formations, although wavelength decreases from lower Kope to the upper Fairview Formation, was ascribed to possible reduction of ripple height by erosion (Hofmann, 1966b, p. 874); water depth probably was greater than the one meter suggested by relating our data to Allen's results.

A low relative abundance of limestone beds in the Kope Formation may indicate deposition of these sediments in a quieter environment or on a stabilized bottom. However, the basin must have had some tidal activity to account for the formation of ripple marks and cross-laminae. The polymodal distribution of ripples in the middle third of the Kope Formation (fig. 14B) reflects stronger tidal-current activity during the accumulation of those beds.

The decrease in ripple-mark wavelength from the Kope to the upper third of the Fairview Formation (fig. 6) might be attributed to a shallowing of the sea, a slackening of currents, a coarsening of average particle size or reduced viscosity of the water, by warming, as did Hofmann (1966b, p. 884, 885). One can even give some credence to a progressive warming of the Cincinnati sea by pointing to the increased limestone in the Fairview and to corals in the rocks of Richmond age. However, Osborne (1968, p. 2148), in an area intermediate to those studied by Hofmann (1966b) and by the present authors, found no such difference in Kope and Fairview wavelengths. Osborne's findings rule out dependence upon temperature changes, and the rocks and fossils argue against control of viscosity by changes of salinity.

Changes in average particle size with stratigraphic position have not been recognized, but the concept has no certain meaning in these shell-hash limestones (Hofmann, 1966b, p. 884). Our field observations do not suggest any systematic changes in particle size with time. Slackening of currents might be associated with shallowing of the sea, but no independent evidence of shallowing was reported by Hofmann (1966b) or was recognized by us, and eustatic shallowing would have affected eastern Hamilton County equally.

At least one hypothesis remains to explain (1) the reduction of ripple wavelength with time in western Hamilton County (Hofmann, 1966b) and in Brown and Adams Counties (this paper), and (2) the absence of any such change in eastern Hamilton County (Osborne, 1968). It depends upon the concept that the carbonate beds formed preferentially on a shoal area, and that the high-limestone units thinned down into and sloped down into somewhat deeper, pelitic bottoms. This view was suggested by Weiss and others (1965) and has been developed by Hofmann (1966a), Ford (1967), and Osborne (1968).

According to this view, the depositional strike was subparallel to the isopachs (fig. 16); regionally, the area of eastern Hamilton County was within rather than marginal to this shoal. Persistent deposition of carbonates on the margins of the shoal might reduce water depth at a point consistently. It is reasonable to consider that such shallowing occurred in western Hamilton County and in Brown and Adams counties. At the same time, eastern Hamilton County was depositionally more stable because it was south-southwest of the growing margin of the shoal. The stability here suggested for the area studied by Osborne (1968) is supported by estimates of mechanical energy at the depositional site. Osborne (1970) showed that significant differences occurred within the Kope and Fairview Formations, but that no trend in time was discernible. He ascribed the differences of mechanical energy at the depositional site to "small-scale transgressive

and regressive events" (Osborne, 1970). The northwest-trending isopachs of the Fairview Formation (fig. 16) are believed to have been subparallel to depositional slope through Fairview time, and the northwesterly currents of that time formed ripples and cross-laminae as they swept along that gentle shoal.

CONCLUSIONS

The carbonates of the Kope and Fairview Formations in Brown and Adams Counties show the diagnostic characteristics of local formation and deposition in a shallow, agitated environment. Pelitic strata seem to have the features of sediments of quieter water or a stable bottom. Directional data of cross-laminae and ripple marks in limestone beds were collected from 101 localities. The directional significance of these structures is shown for several subdivisions of the Kope and Fairview Formations, and for the units as a whole, and allow some limited generalizations.

The prevailing paleocurrent direction was toward the north-northwest. Although a significant difference exists in western Hamilton County between Kope and Fairview paleocurrent directions (Hofmann, 1966b), no such difference occurs in eastern Hamilton County (Osborne, 1968) or in the area studied. Thus Kope and Fairview paleocurrent directions cannot be discriminated regionally. Significant local differences, however, do exist between the Kope and Fairview ripple wavelengths; ripple marks are larger in the Kope Formation and gradually decrease in size upward through the section to the upper Fairview Formation.

Regional differences in prevailing paleocurrent directions (as reported by Osborne, 1968, and this paper) and temporal differences, as between the Kope and Fairview (Hofmann, 1966b) can all be made coherent consequences of a shoal with a nose pointing northeastward in eastern Hamilton County. Currents moved west-northwest along it in Brown and Adams Counties, were somewhat more mixed and more southerly in eastern Hamilton County, and moved south-southwest in western Hamilton County. The ripple marks of the Kope and Fairview are believed to have been formed—and sometimes cross-laminated—by surf, tidal, or wind-driven currents, and to have been modified by waves.

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